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**PROCESS FOR THE WALL IRONING OF A PRODUCT IN SHEET FORM,  
AND A WALL IRONING TOOL**Field of the Invention

The invention relates to a process for the wall ironing of a product in sheet form, which is formed from a metal sheet coated on at least one side with a layer of plastic, the wall-ironing tool comprising a forming surface which the product with a plastic coating layer moves along during the wall ironing, and the forming surface being at an entry angle with respect to the direction of movement of the product. A process of this nature is in widespread use for the production of a can comprising a base and a tubular body, although the invention is not limited to this particular application.

Background of the Invention

The entry angle forms an important parameter in wall ironing. It has been found that with a very small entry angle the spreading force, that is to say the force which acts on the forming surface transversely with respect to the direction of movement of the product, becomes very high. For example, in the case of wall ironing of cans, this may lead to extreme loads being imposed on the wall-ironing ring used, which may consequently be damaged or even break.

Selecting a larger entry angle runs the risk of the plastic layer breaking and being stripped off the metal sheet. This is because a larger entry angle results in a greater longitudinal force being exerted on the plastic layer in the direction of movement, with the result that the stress in the said plastic layer exceeds a fracture limit.

Proposals have previously been made for making the process more suitable for working with plastic-coated metal sheet. In European Patent EP 0,298,560, it is proposed that additional lubrication be used during the wall ironing, and specific entry angles are proposed for successive wall-ironing rings. Nevertheless, there is a continuing need to work with larger entry angles, in order to be able to achieve longer service lives of the wall-ironing tool. The present invention now offers a solution enabling the risk of the plastic layer breaking and being stripped off during wall ironing to be reduced, so that larger entry angles can be used.

Brief Description of the Figures

The invention is based on making use of the observed fact that many plastics materials exhibit a higher fracture limit during forming as the pressure on all sides increases. The appended figure shows results of the correlation between the forming rate ( $ds/dt$  in  $s^{-1}$ ), plotted on the horizontal axis, and the yield stress  $\sigma_y$  in MPa, plotted on the vertical axis, and the prevailing pressure  $P_0$  in MPa on all sides. This figure works on the basis of a polyethyleneterephthalate (PET), with lines illustrating results of model studies and crosses indicating the results of experiments. It can be clearly seen from this figure that the yield stress is considerably higher as the pressure on all sides rises. The object of the invention is therefore to produce a high pressure on all sides at the location where the coated metal sheet is being wall-ironed using a large entry angle,

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without it being necessary to apply a very high pressure to the entire wall-ironing installation.

Detailed Description of the Preferred Embodiments

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The invention therefore consists in the fact that the entry angle varies over the length of the forming surface, in the direction of movement of the product past the forming surface, this entry angle being smaller in a starting zone of the forming surface than in the subsequent zone thereof. The result of this measure is that, in the starting zone with the small entry angle, a high pressure on all sides is built up in the material, and this pressure is maintained during the subsequent forming in the subsequent zone with a larger entry angle. In the zone where the actual forming takes place, a high pressure prevails on all sides, yet nevertheless a relatively low spreading force is exerted on the forming surface (for example a wall-ironing ring).

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The high pressure which is generated on all sides in the plastic layer may relax slightly towards the chamber after the wall-ironing tool has been passed, towards the end of the zone with the larger entry angle. This may mean that the fracture stress of the plastic material is reduced again at that location, causing it to fracture and be stripped off by the wall-ironing tool. For this reason, it has proven advantageous for the forming surface in an end zone to again be at a smaller entry angle than in the intermediate zone.

An improvement is also achieved if the forming surface, following the zone with the largest entry angle, comprises a so-called land zone, with an entry angle of  $0^\circ$ . The length of this land zone may be between 0.3 and 1.5 mm.

In one possible application of the invention, the entry angle may have a fixed value in each of the said zones. However, under certain circumstances it may be preferable for the entry angle to change smoothly over the length of the forming surface. This prevents sudden changes in stress in the material to be wall ironed, so that, under certain circumstances, the wall ironing can proceed more successively.

In the preferred embodiment of this smooth change, the transitions between the successive zones, and/or the zones themselves, run in the form of an arc of a circle. Good results are obtained if the radius of this arc is between 0.1 and 10 mm long.

Particularly if the novel process is used for the wall ironing of a product which ultimately acquires the shape of a can, it is advantageous for the wall-ironing tool to comprise a plurality of wall-ironing rings of the type described above. In particular, it has proven advantageous for between 60 and 90% of the total wall thinning to be produced by the corresponding forming surface in the zone which runs at the largest entry angle, the so-called main zone. A further improvement is obtained if between 10 and 30% of the total wall thinning is produced by the corresponding forming surface in the starting zone. Furthermore, it is advantageous, if an end zone is also being used, for less than 30% of the total wall thinning to be produced by the corresponding forming surface in this end zone.

As explained above, it is possible, when using the novel process according to the invention, to use a larger entry angle in particular in the intermediate main zone, allowing the mechanical load on the forming surface, i.e. the wall-ironing ring, to be reduced. Despite this larger entry angle, it is generally possible, by using a starting zone and an end zone with a smaller entry angle, to prevent the plastic coating layer from yielding and being stripped off.

When using various plastics in various layer thicknesses and on various types and thicknesses of metal sheet, the limiting conditions for the entry angle in the intermediate zone and the entry angle and the length of the starting zone and the end zone will generally be different if it is desired to work using conditions which are optimal for all ironing without there being any risk of the plastic layer fracturing and being stripped off. It has been found that for various materials applications, the optimum conditions can be determined by means of experiments using forming surfaces (for example of wall-ironing rings) in which the length of the starting zone and/or the end zone is varied.

During the wall ironing of a plastic-coated metal sheet, the following functional relationship applies to the yield stress  $\sigma_v$  (in MPa) in the plastic:

$$\sigma_v = \frac{3}{\sqrt{3} + \mu} \cdot [\tau_0 \ln(2\sqrt{3} \cdot A_0 \cdot d\varepsilon/dt) + \mu P_0], \text{ where:}$$

$P_0$  is the pressure in MPa prevailing on all sides in the plastic;

$\tau_0$  is a base level for the yield stress in MPa;

$d\varepsilon/dt$  is the drawing speed of the plastic being formed in  $\text{sec}^{-1}$ ;

$\mu$  is a unit-free parameter which represents the pressure sensitivity of the plastic;

$A_0$  represents a time constant (in sec) which is related to the relaxation behaviour of the plastic.

According to the invention, it has been found that the wall ironing of a coated product in sheet form at an elevated pressure on all sides  $P_0$  only takes place successively if the values of the parameters  $\mu$ ,  $\tau_0$  and  $A_0$  of the plastic used for the coating satisfy specific boundary conditions. These values must be as follows:

$$\mu \geq 0.03; \tau_0 \geq 0.60 \text{ MPa and } A_0 \geq 2.0 \times 10^{19} \text{ sec.}$$

It is preferable to use plastics in which the parameters are as follows:

$$\mu \geq 0.047; \tau_0 \geq 0.90 \text{ MPa and } A_0 \geq 3.0 \times 10^{19} \text{ sec.}$$

It has been found that what is known as the glass transition temperature  $T_g$  of the plastic is important in the wall ironing of a plastic-coated metal sheet.  $T_g$  is the transition point for the properties of the amorphous range in the plastic. In principle, below  $T_g$  free movement of the main chain of the polymer is impossible. Above  $T_g$ , this freedom of movement is possible, leading to the hardness of the material falling by orders of magnitude. Since many plastics are partially crystalline, and this part partially retains its strength up to the melting point, many plastics materials can still be used very well up to temperatures far above  $T_g$ .

In the case of wall ironing, the level of  $T_g$  is important because the plastic must still have a relatively high mechanical strength during the wall ironing. A plastic coating with a low  $T_g$  may possibly acquire sufficient strength by building up a very high pressure in the wall-ironing tool. However, just outside this pressure zone the plastic is so "weak" that it is immediately pressed away and scrapped off.

During the wall-ironing process, a considerable rise in temperature takes place in the ironed material. This temperature may rise to approx.  $200^\circ\text{C}$ .

It has been found that a plastic-coated metal sheet can be successfully wall-ironed if the  $T_g$  of the plastic is sufficiently high under various conditions. The  $T_g$  at atmospheric pressure,  $T_{g, 1 \text{ atm}}$ , and the  $T_g$  when the plastic is under a pressure on all sides of 600 MPa,  $T_{g, 600 \text{ MPa}}$ , have proven particularly important in this context. According to the invention,  $T_{g, 1 \text{ atm}}$  and  $T_{g, 600 \text{ MPa}}$  must be as follows:  $T_{g, 1 \text{ atm}} \geq 30^\circ\text{C}$  and  $T_{g, 600 \text{ MPa}} \geq 200^\circ\text{C}$ . Preferably,  $T_{g, 1 \text{ atm}}$  must be as follows:  $T_{g, 1 \text{ atm}} \geq 70^\circ\text{C}$ .

In addition to the process described above, the invention also relates to a wall-ironing tool, in particular a wall-ironing ring, comprising a forming surface, past which a sheet-like product can be moved during the wall ironing, which forming surface is at an entry angle with respect to the direction of movement of the product. This wall-ironing tool is characterized in that the entry angle varies over the length of the forming surface, in the direction of movement of the product, this angle being smaller in a starting zone of the forming surface than in the subsequent zone thereof.

Numerous preferred embodiments of the wall-ironing tool according to the invention have been explained in the preceding description of the novel process, to which reference is made here.

A particular preferred embodiment of a wall-ironing ring according to the invention is also that this wall-ironing ring is under a radial prestress on its outer circumferential surface, due to a strip or wire which has been wound around it under stress.

Wall-ironing rings are generally known, as are the associated terms such as entry angle, main zone and land zone.

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Therefore, there is no need for the wall-ironing rings discussed to be explained in more detail in a description referring to figures.

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